

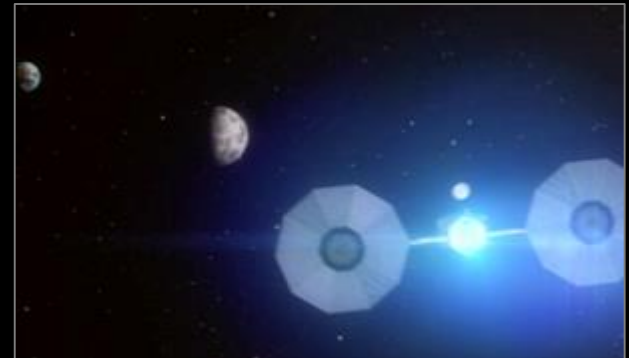
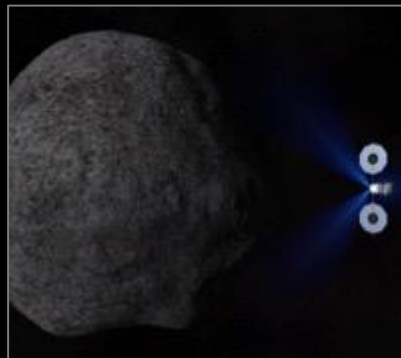
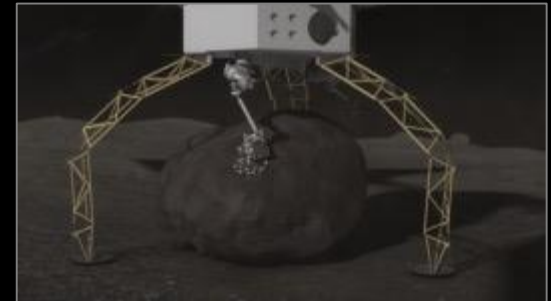
MBSE Practice and Activities on ARRM

Thomas Randolph

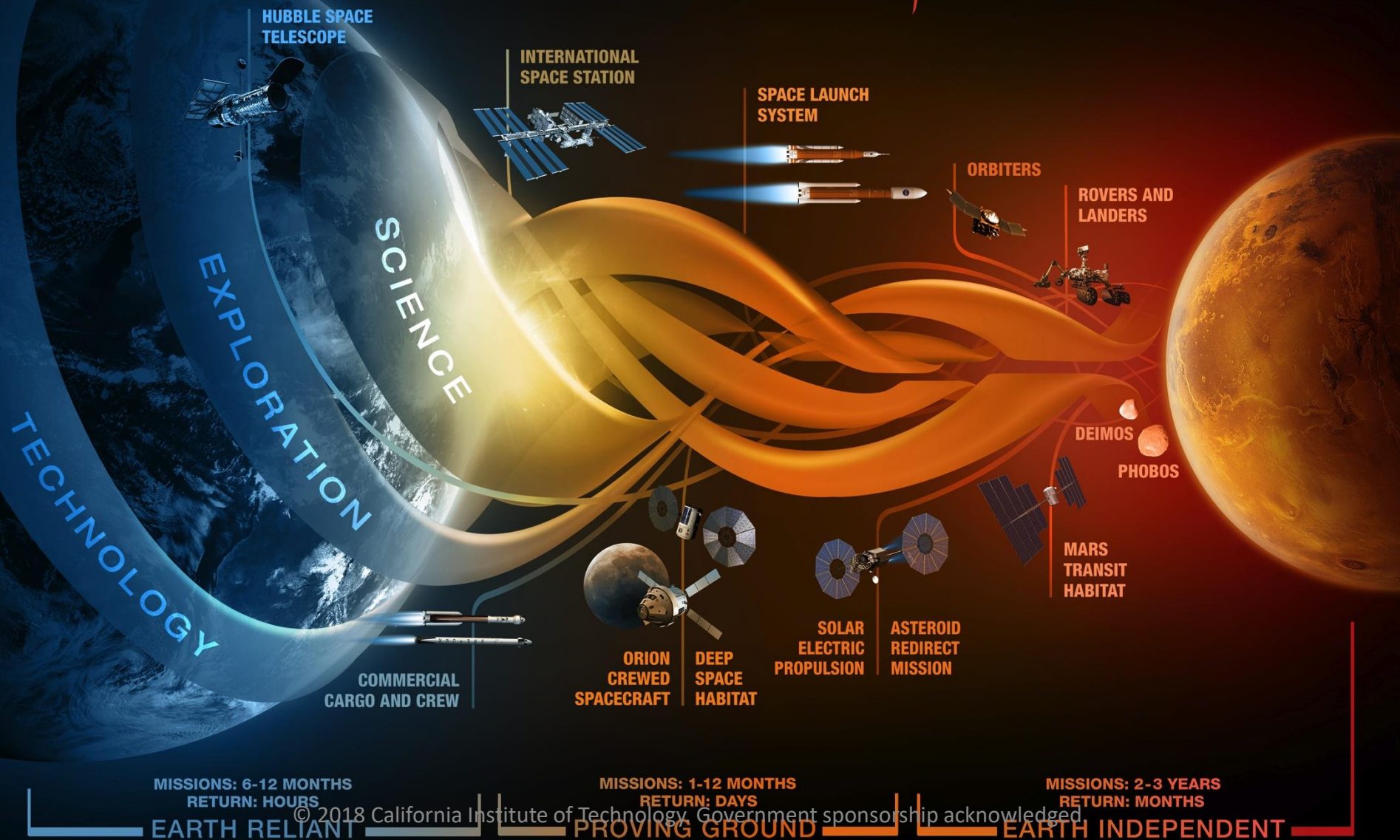
Jet Propulsion Laboratory

California Institute of Technology.

February 9th, 2018



JOURNEY TO MARS



MISSIONS: 6-12 MONTHS
RETURN: HOURS

MISSIONS: 1-12 MONTHS
RETURN: DAYS

MISSIONS: 2-3 YEARS
RETURN: MONTHS

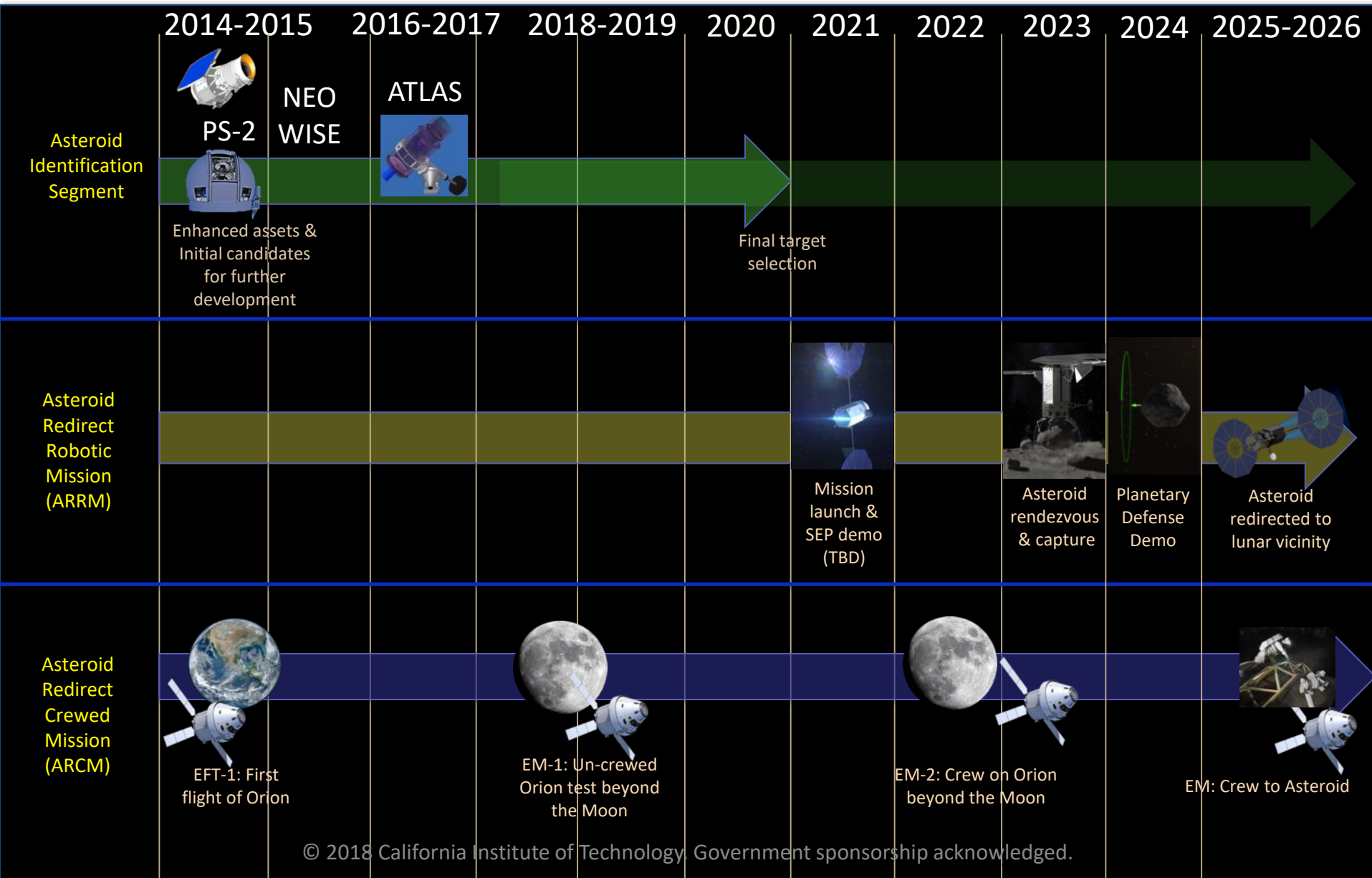
EARTH RELIANT

PROVING GROUND

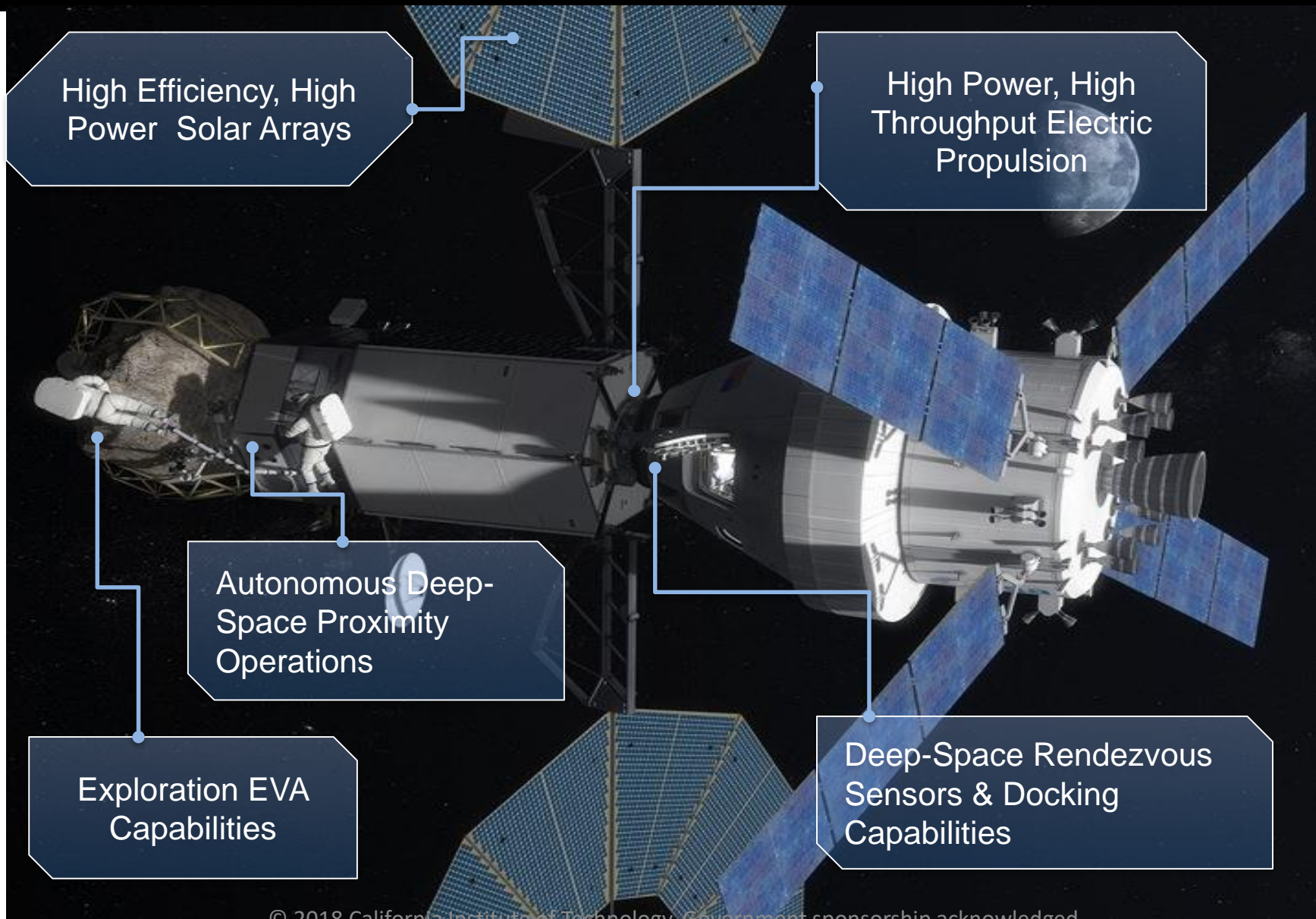
EARTH INDEPENDENT

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Asteroid Redirect Mission Concept Alignment Strategy

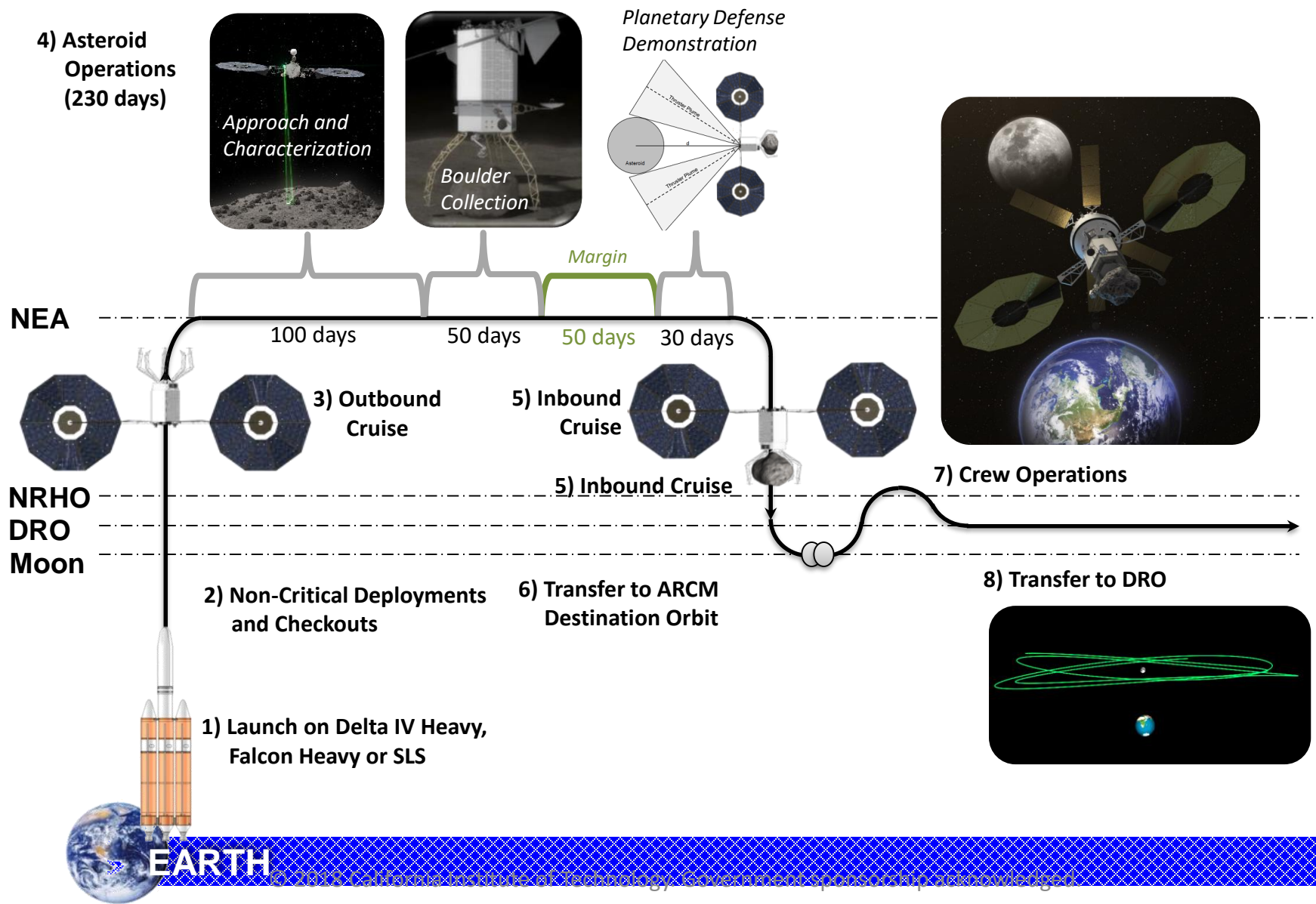


Key Technology Highlights

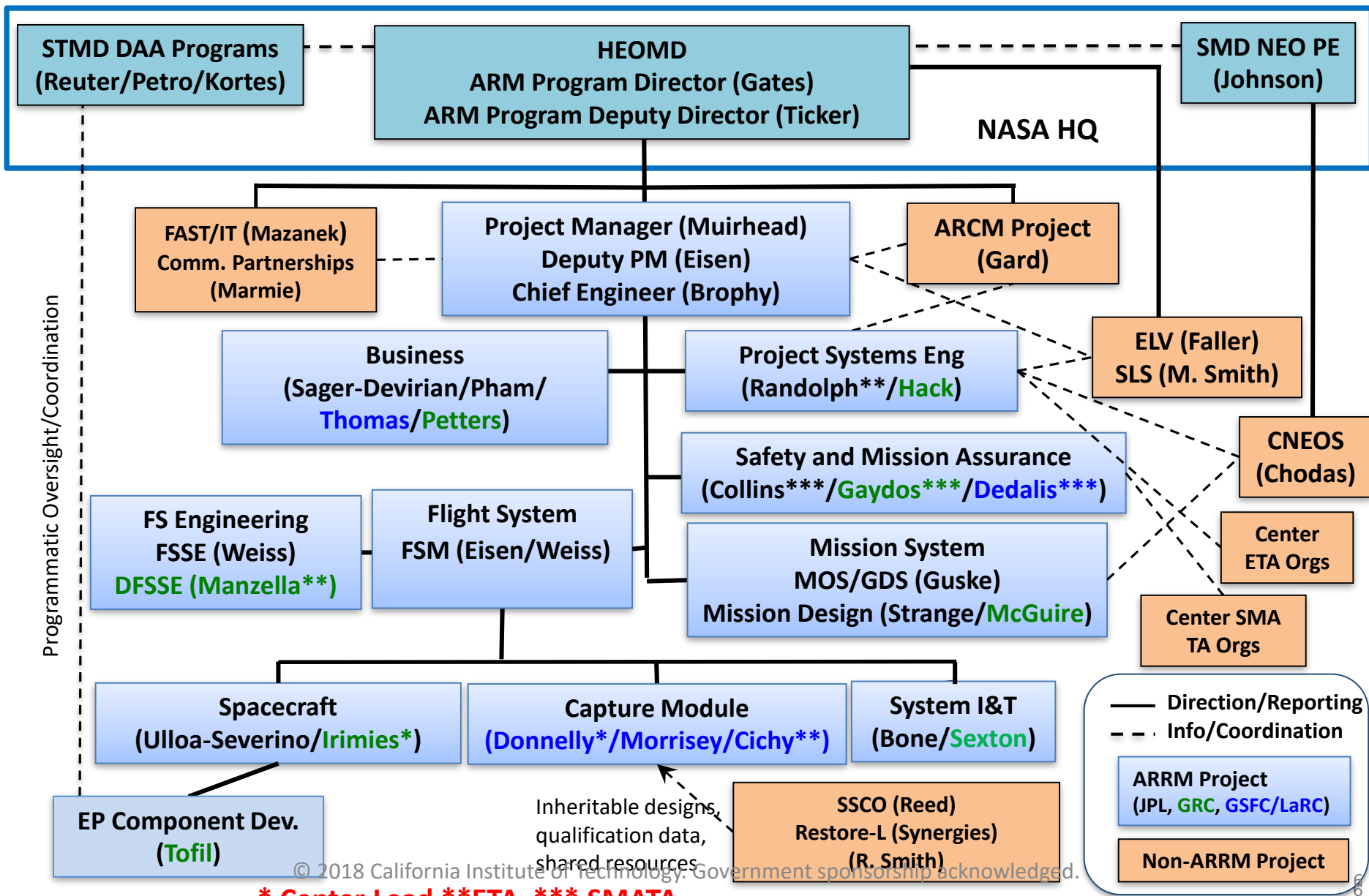


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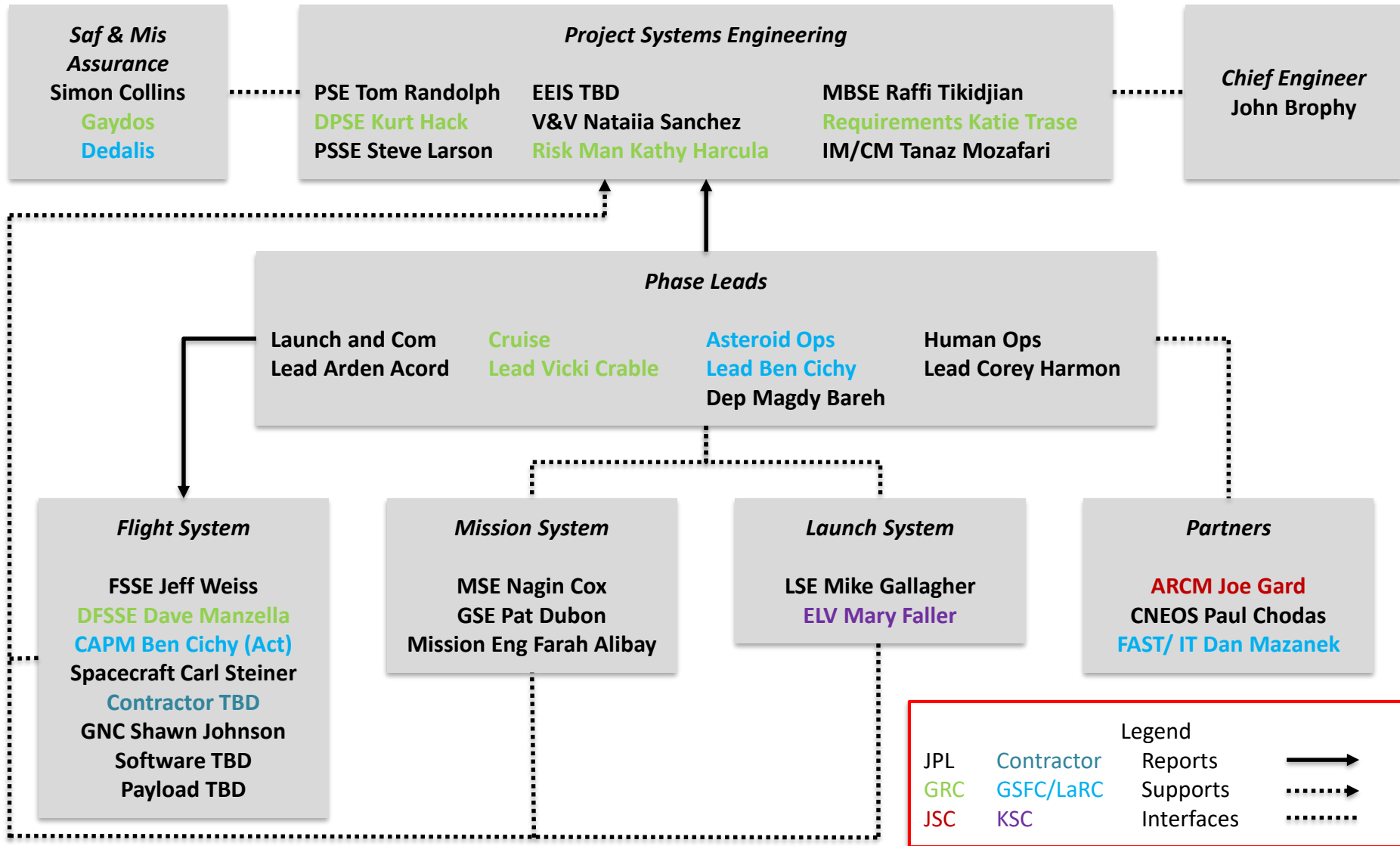
ARRM Mission Concept Overview



ARRM Organization



System Engineering Org Chart





- **Multi Center Team**

- Many more organizations than normal (JPL, JSC, GRC, KSC, LaRC, GSFC, Contractor)
- Much more fully integrated into the team (the PSE team has substantial core roles performed by people at other NASA centers)

- **Technology Demonstration on a Large Scale**

- High power arrays and thrusters with commercial possibilities
- Asteroid and astronaut proximity operations

- **Many New Operational Modes**

- Picking up a boulder
- Planetary defense
- Exploration robotic spacecraft docking to a manned spacecraft

- **Out of Sync Project Elements**

- Late start of spacecraft contractor due to funding constraints
- Human mission does not launch until well after we do

System Engineering Function Tailoring

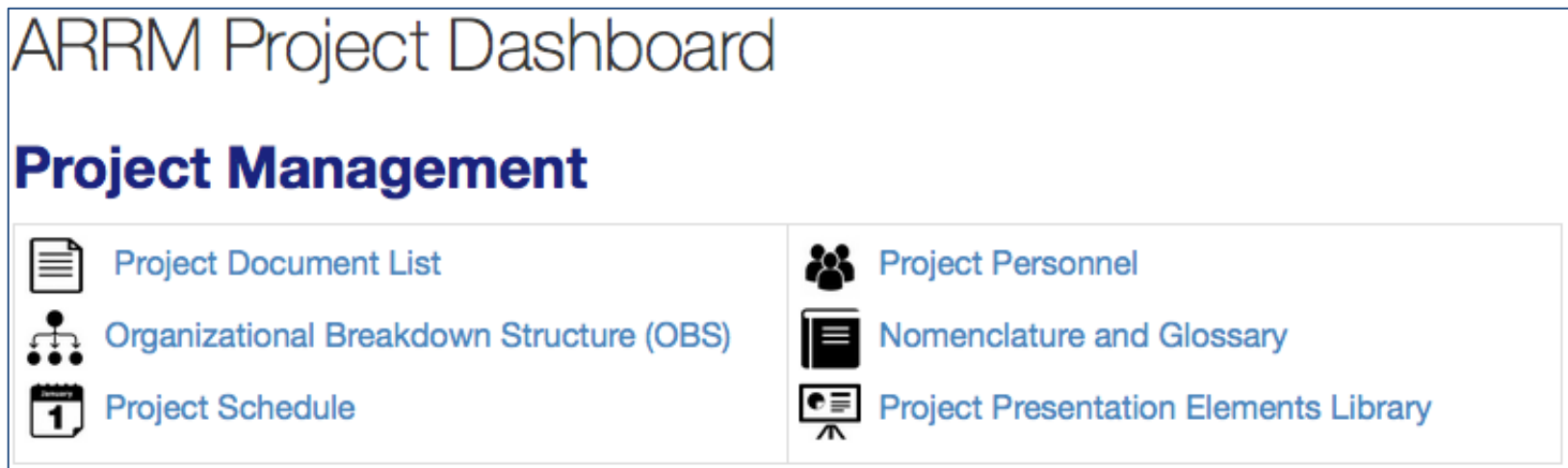


Functions	ARRM Tailoring
Task Management	Cloud integrated badgeless roles
Architecting	Model allocation of functions to systems
Requirements	Link requirements to functions
Analyze & Characterize the Design	Timeline link to model constraints
Technical Resource & Perf Management	TBD waiting contractor selection
Interfaces	IRD information linked in the model
Verification and Validation	Focus on activities and functions
Reviews	Lien review cycle
Risk Management	Integrated process linked to liens
Manage & Control Req & Design	Release synced to model snapshots



- **Need:**
 - Info Management opportunity to support multi-organization, distributed team of stakeholders
 - Exploration of leaner implementation of proven NASA Systems Engineering (SE) processes
- **Leveraged earlier MBSE applications at JPL**
 - Orion EFT-1, Europa Clipper
 - Institutional process modernization effort (Integrated Model Centric Engineering, Systems & Software Computer Added Engineering)
- **Infrastructure: secure cloud-based environment for modeling, task, risk & project data management environment**
 - accessible by JPL and NASA team members
 - collaborative modeling server for System Model
 - web-based reporting from System Model (View Editor tool) w/ export to traditional reporting forms (pdfs, doc, csv)
 - web-based task tracking: SE tasks, MBSE capability development (including bug tracking)
 - info management: project portal, doc repository, wikis, chat & IM

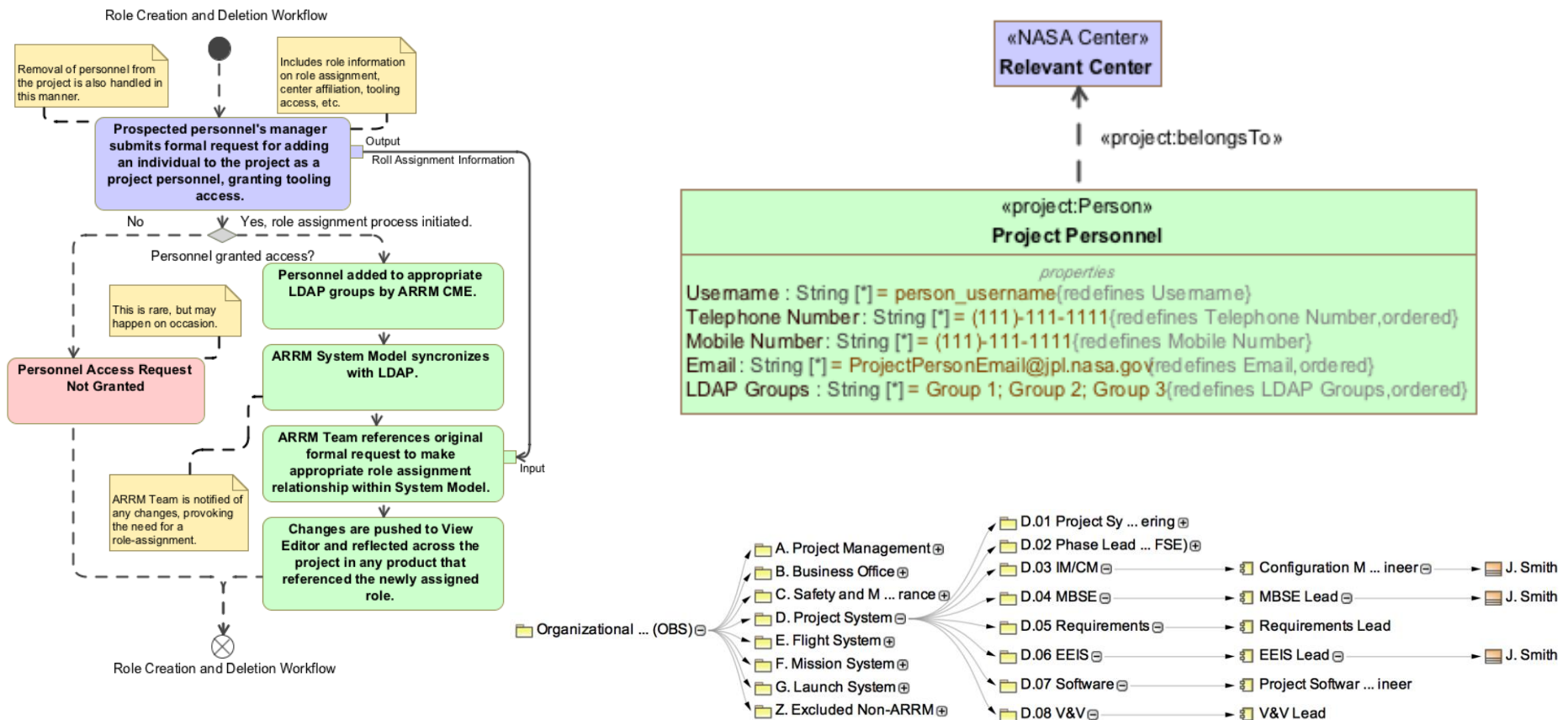
- Document metadata definition for use in document cover page generation and for tracking document ownership, approval & release state information
- Project metadata definition for use of personnel role descriptions & assignments
- Status of, including release schedule reporting with regards to project milestones and, access to latest in-work & approved documentation



Personnel Metadata Definition



- Standardized process for definition of personnel, center affiliation & roles assignments
- Organizational Breakdown Structure (OBS)
- Tool & automation of personnel metadata via Lightweight Directory Access Protocol (LDAP)

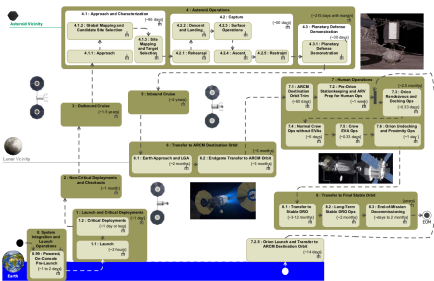


MBSE for ARRM Technical Architecture Development

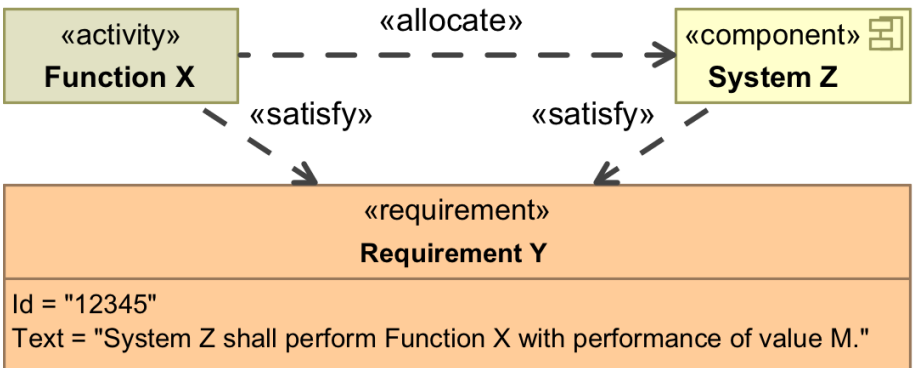
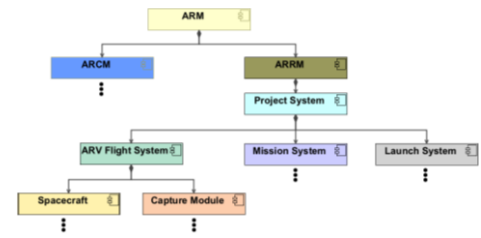


Functional Requirements Validation: development & validation of technical requirements that map to activities & functions in mission operational concept as performed by mission systems

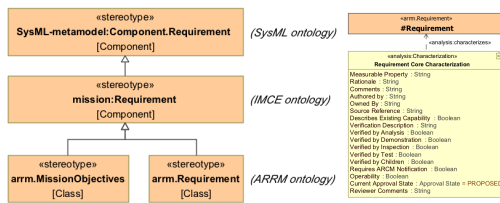
Mission Operational Concept Definition



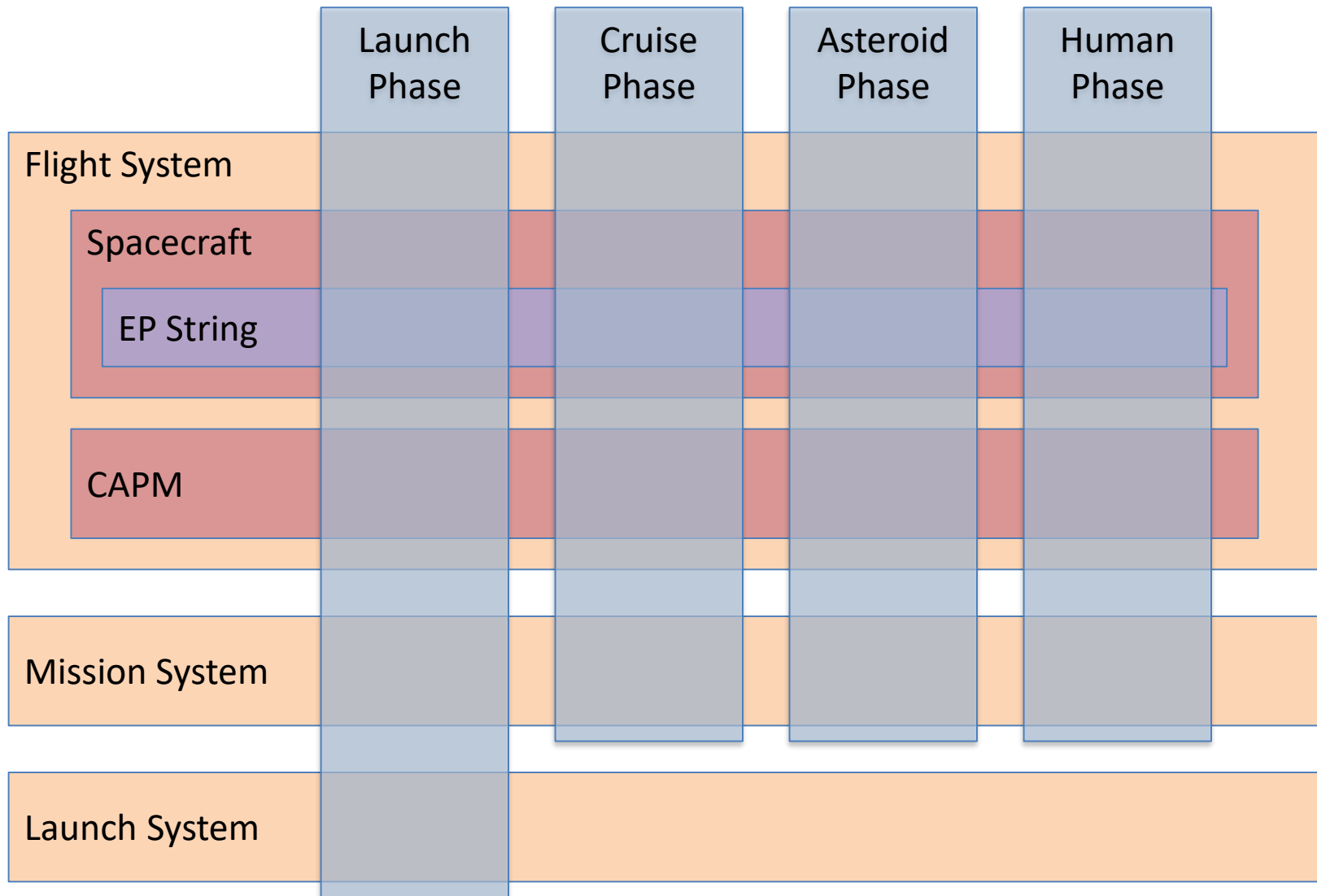
System Decomposition & Characterization



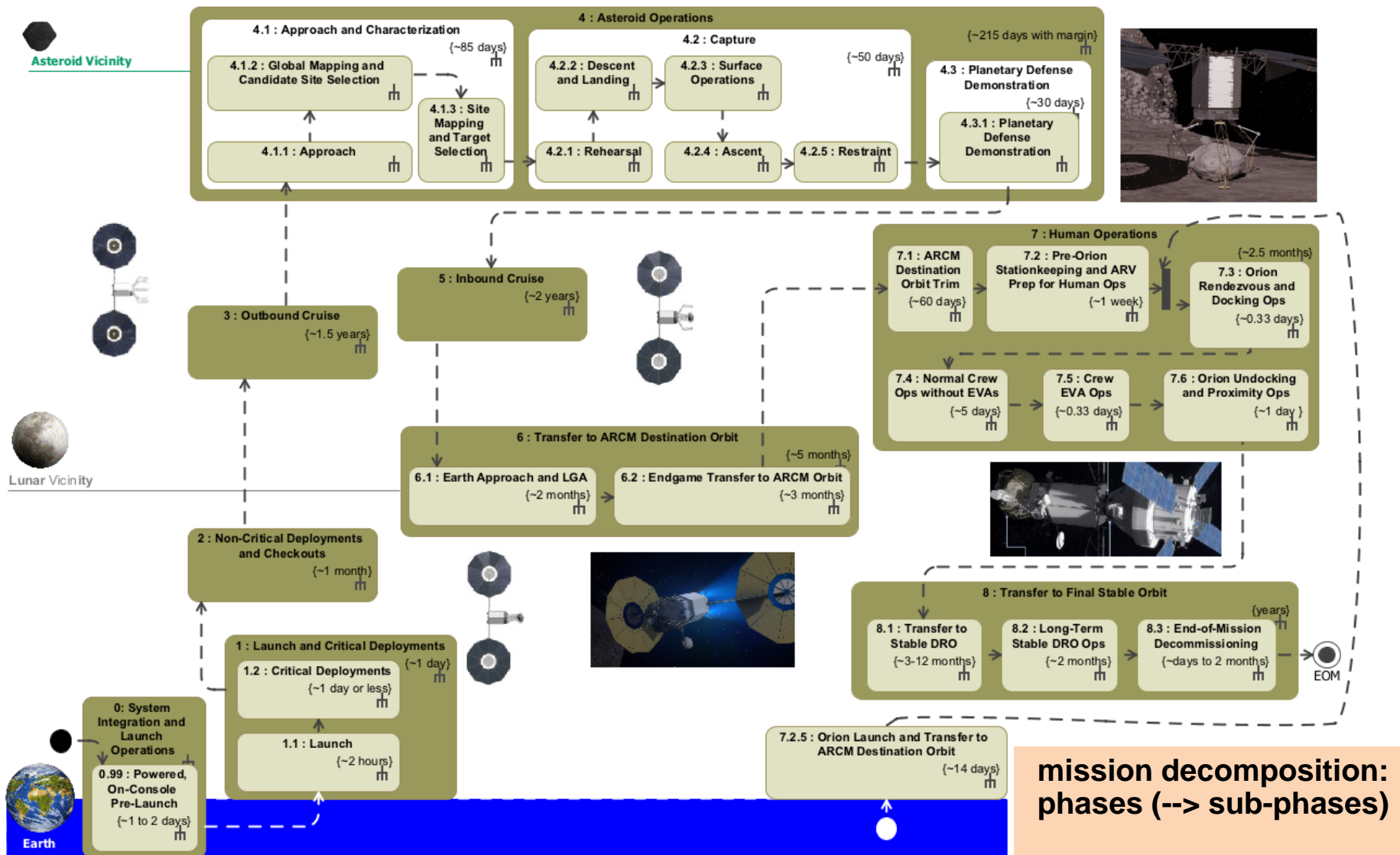
Functional Requirements Development & Validation



Mission Phases Versus Project Systems



Mission Operational Concept Definition



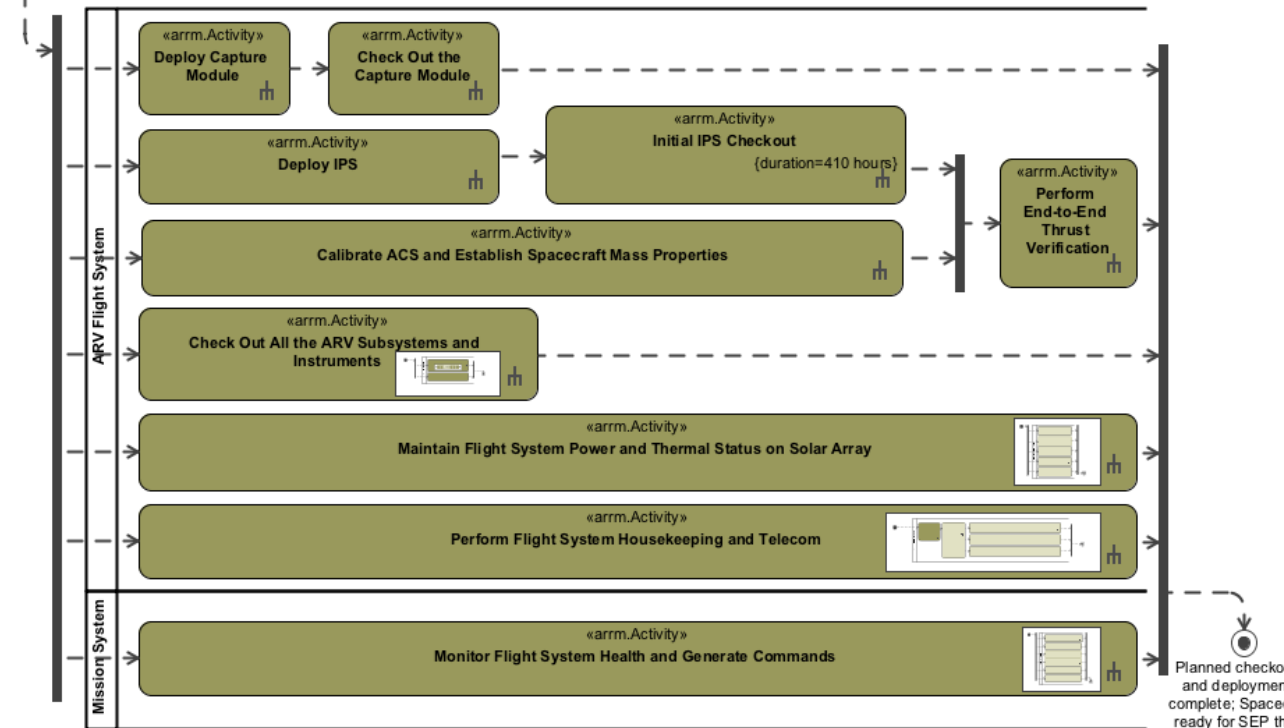
Mission Operational Concept Decomposition



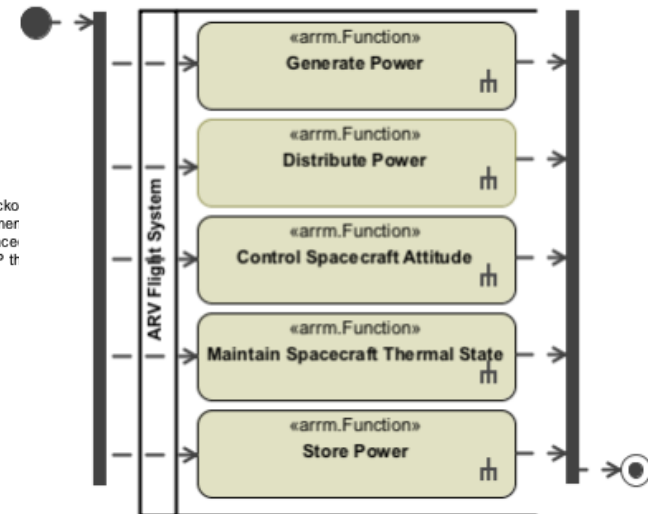
mission decomposition: phases (--> sub-phases) --> activities --> functions

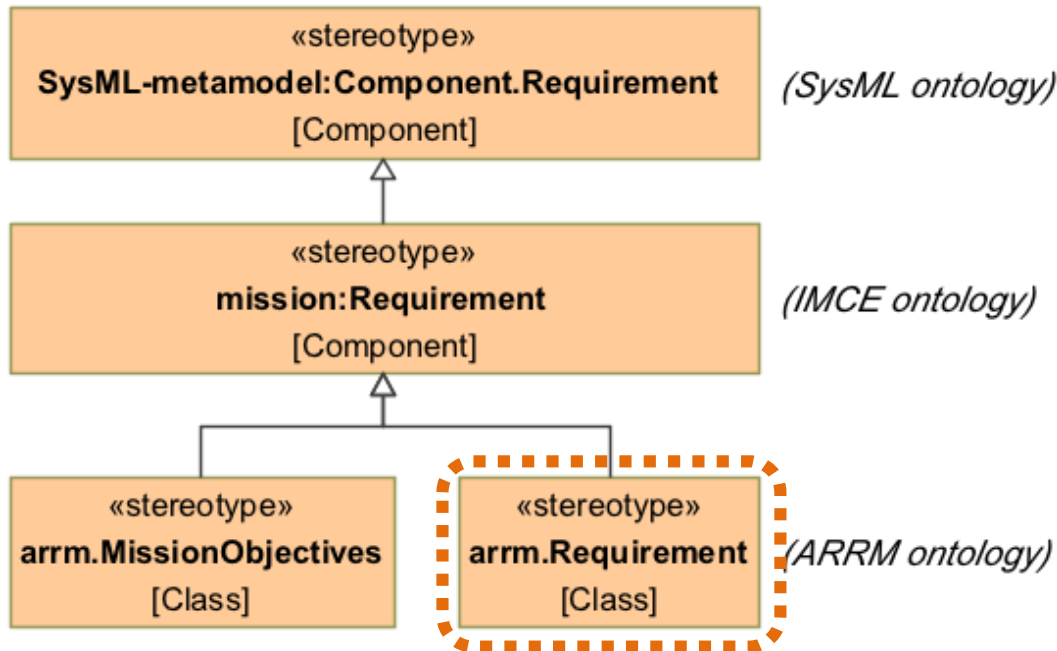
[Non-Critical Deployments and Checkouts]

solar arrays deployed & in 3-axis stabilized communications

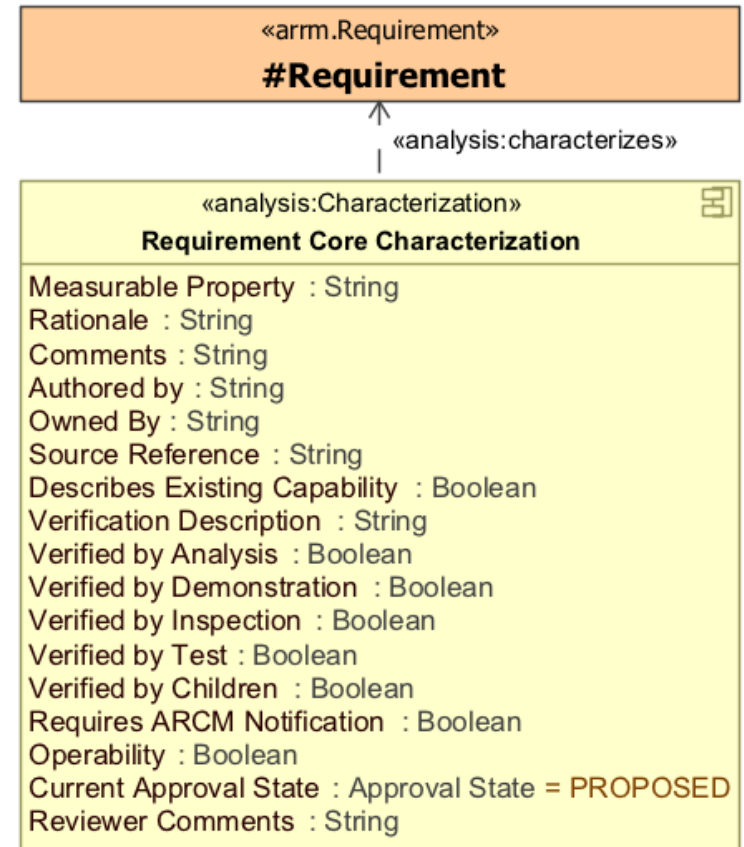


[Maintain Flight System Power and Thermal Status on Solar Array]





characterization for quantitative
and/or **qualitative** analysis

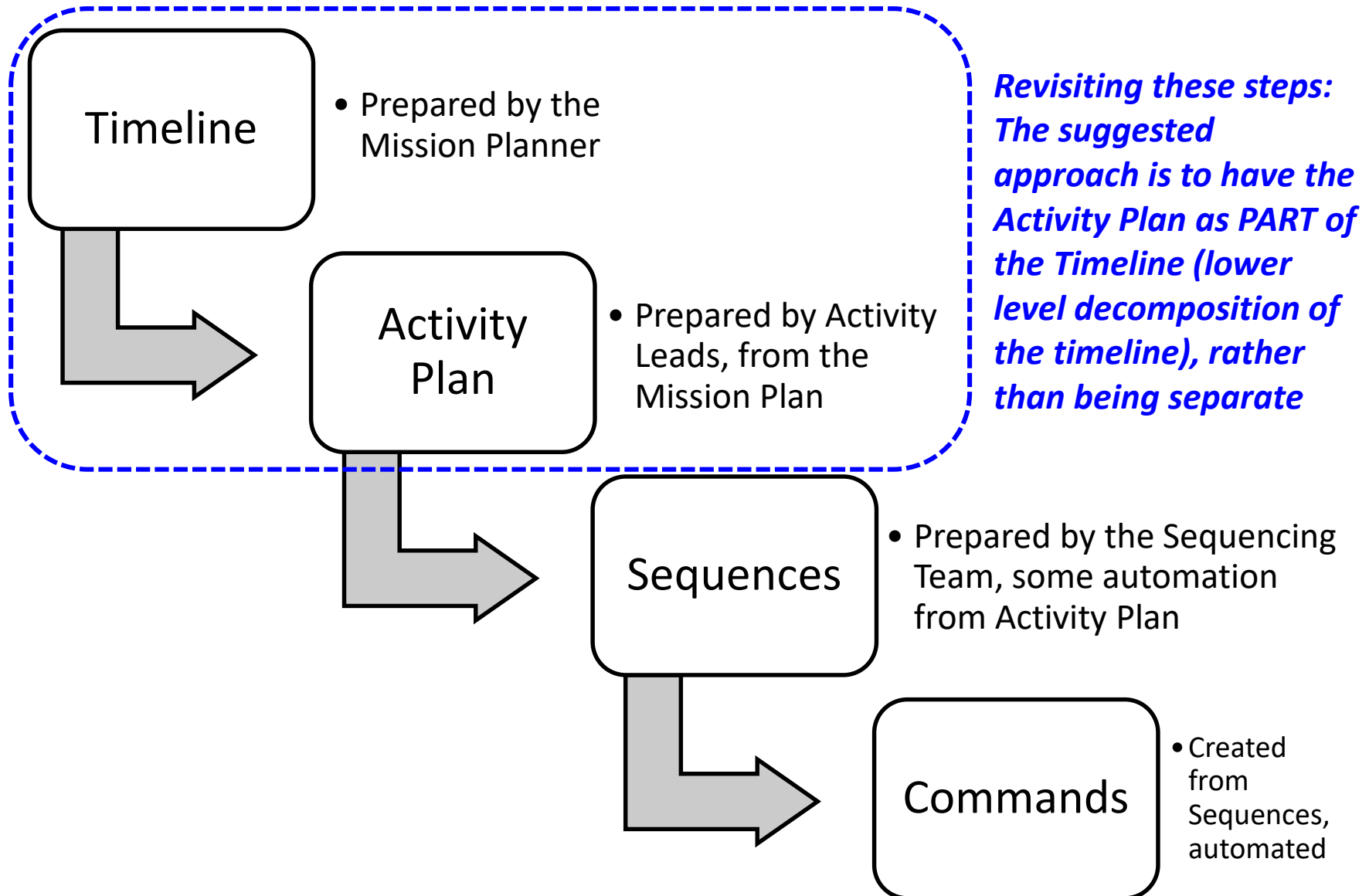




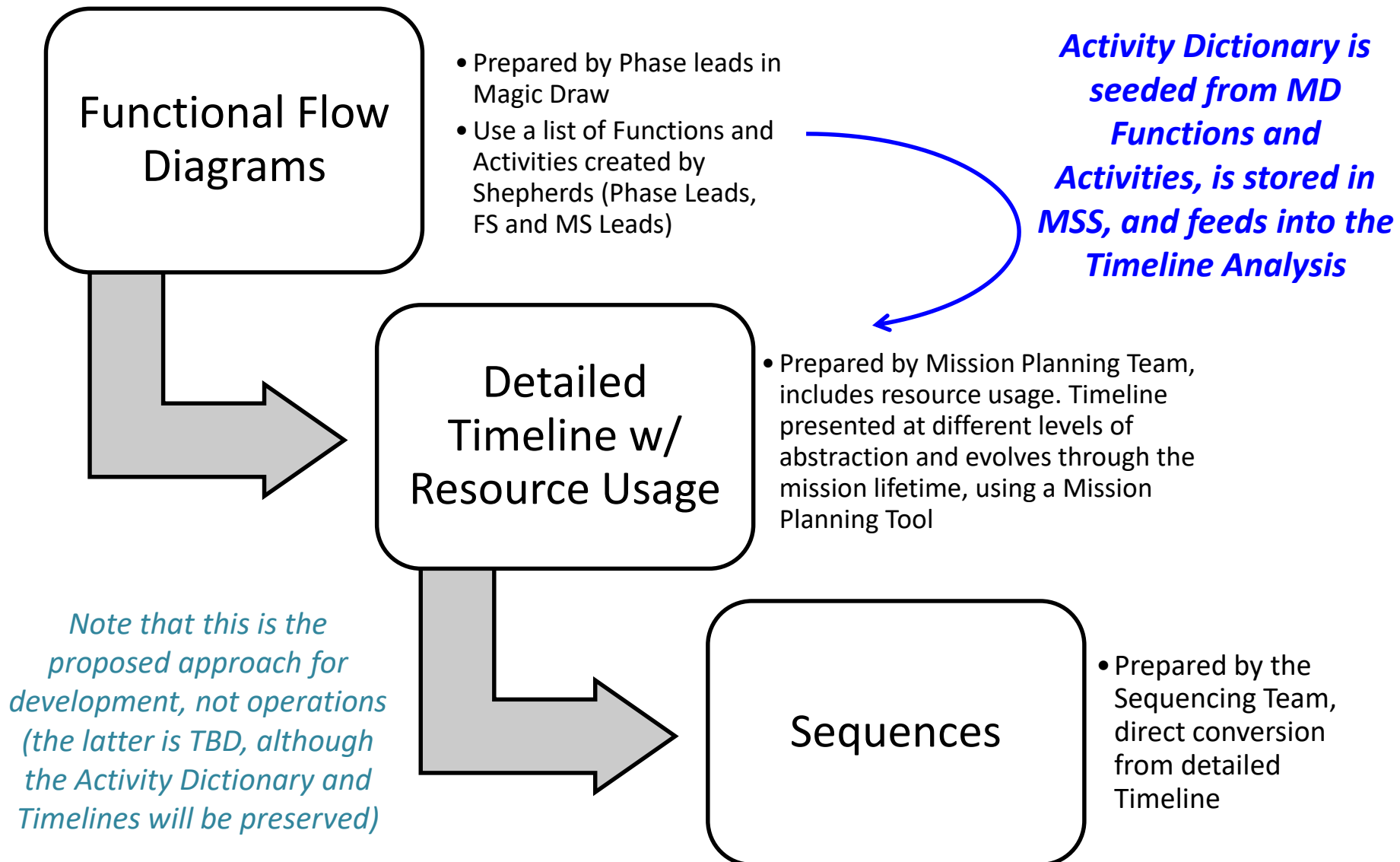
- **Functional Requirements Validation through relationships:**

- requirements are derived from higher-level requirements, which trace to mission objectives
- quality of requirements analyzed through populated content for attributes in characterizations
- identified mission functions, from the OpsCon, that satisfy requirements
- functions are allocated to appropriate performing systems
- requirements are allocated to lower level system(s) for elaboration

Old Mission System Development Approach



ARRM Mission System Development Approach



Interactions with Mission System Tools



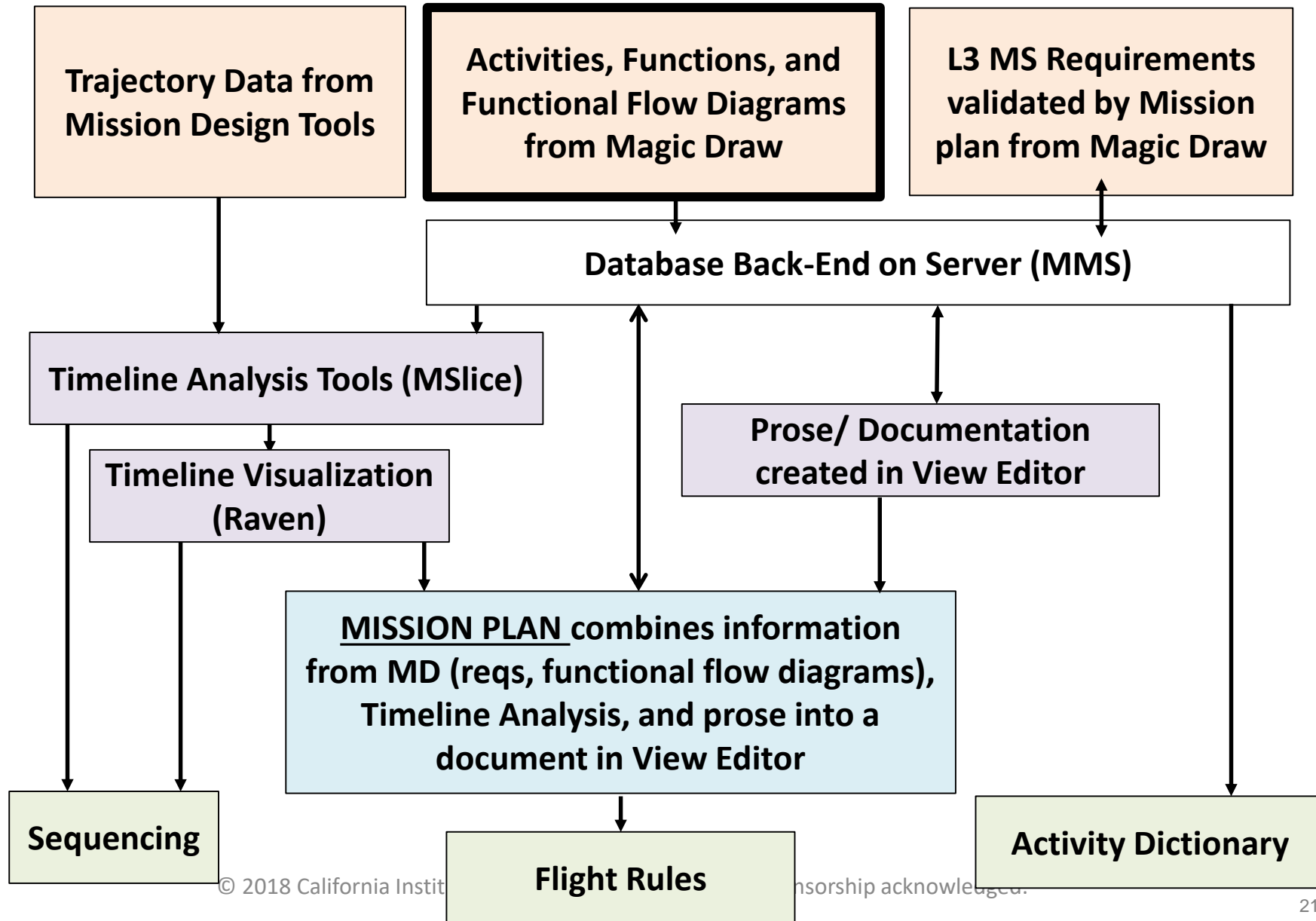
I/p from non
MP Tools

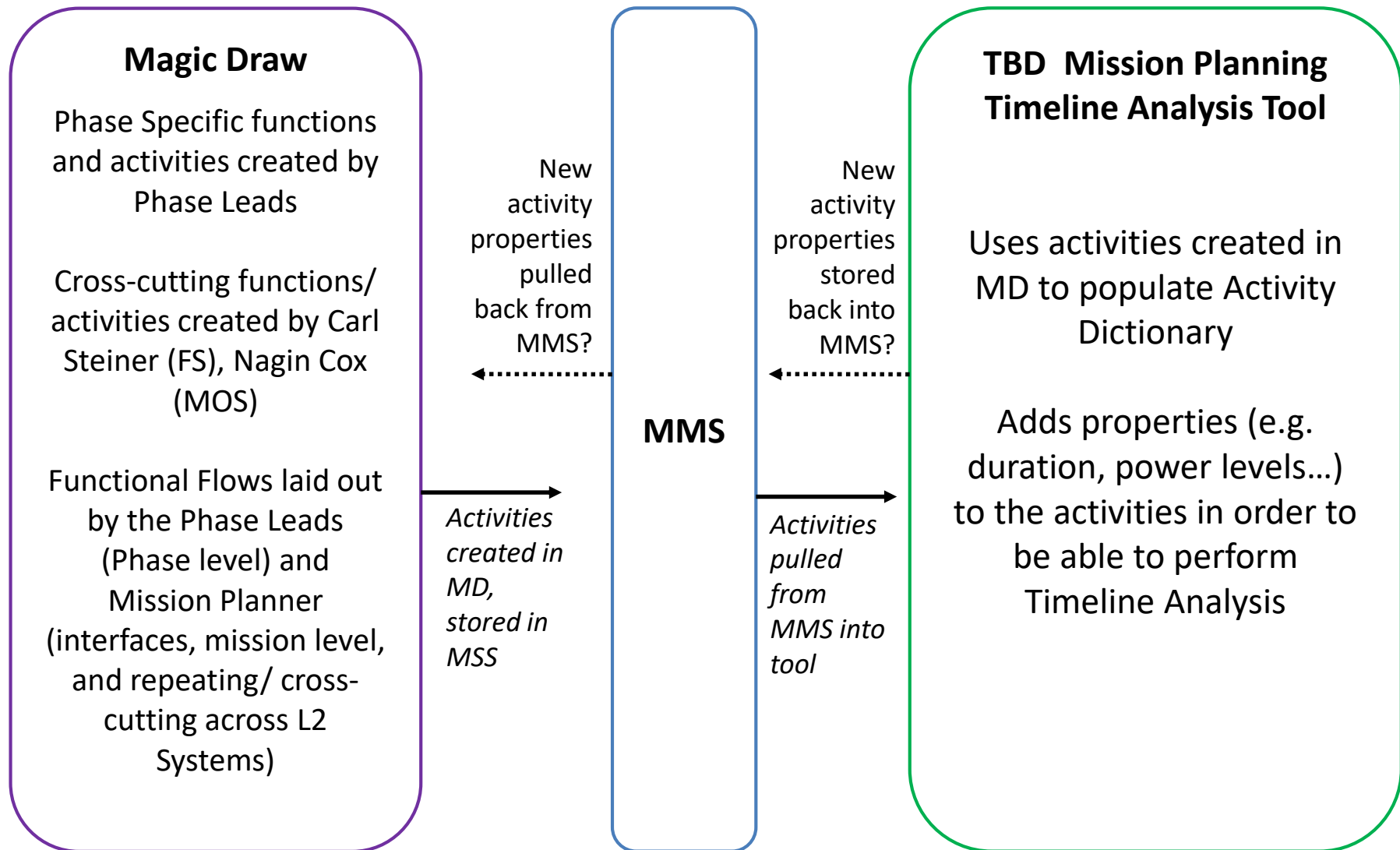
“Model”

MP Analysis

Products

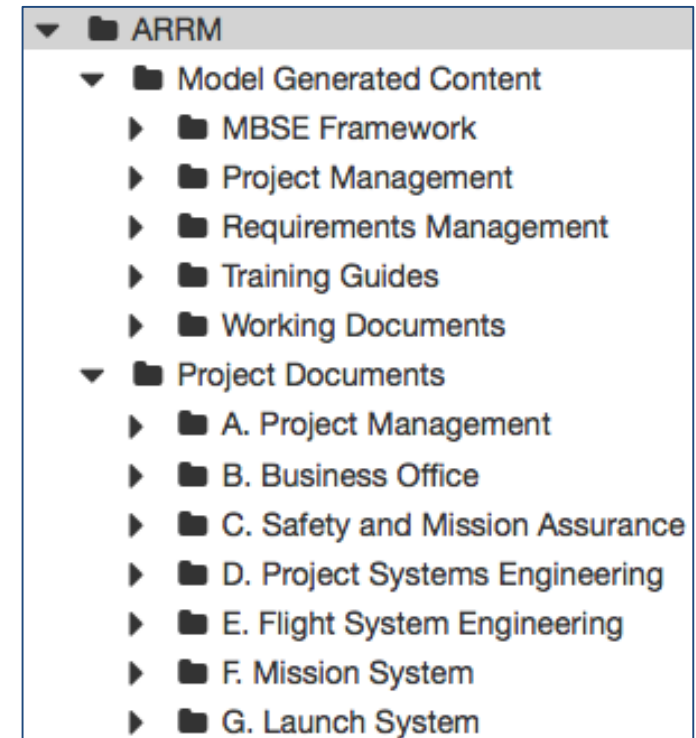
End Use





- **Project documentation is defined & managed in same MBSE-based environment as technical content**

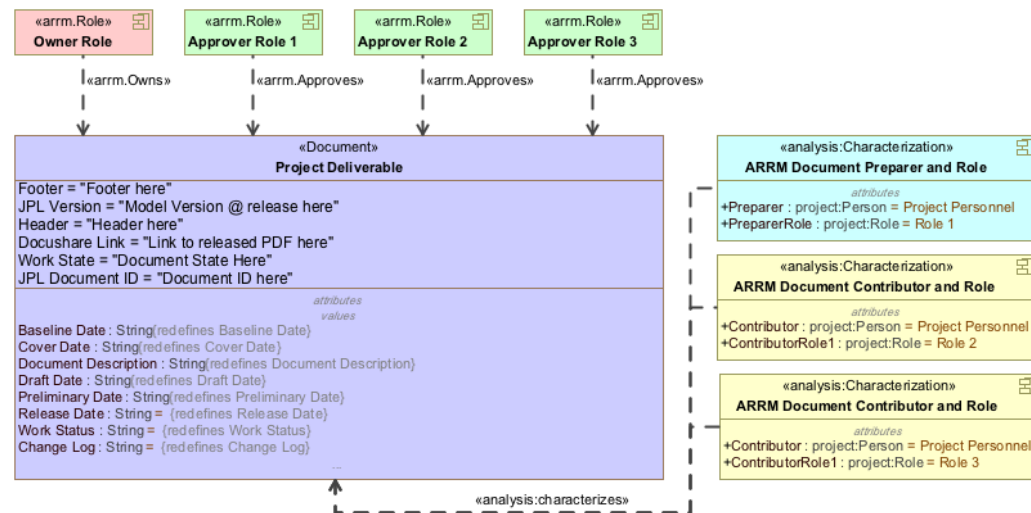
- employs DocGen plugin in web-based View Editor environment
- deployed a centralized project document list
- doc titles (and other doc metadata) sections, tables, and diagrams are just another set of elements in larger System Model
- both technical & programmatic content is integrated into documentation, which is generated and tracked in real-time



Document Management



- documents linked to project milestones, phases & release schedule
- autonomous, uniform formatting of deliverables
- repository of applicable & reference documents
- formal document release process



Document List

OBS	Name	JPL Document ID #	Released Document PDF Link	Document Preparer(s)	Document Owner(s)	Document Approver(s)	Draft Date	Preliminary Date	Baseline Date	Work Status	Revision	Cover Date	Release Date
D. Project Systems Engineering	ARRM Flight-Ground Interface Control Document	JPL D- [redacted]	Click Here for Official Document in Alfresco	Oleg Sindly [redacted]	End-to-End Information Systems Engineer [redacted]	Project Systems Engineer [redacted] Flight System Systems Engineer [redacted] Mission System System Engineer [redacted]	KDP-B - 2016-07-15	KDP-B - 2016-07-15	System Design Review (SDR) - 2017-12-01	Prelim	Prelim	May 12, 2016	May 16, 2016



- **Centralized project document database with up-to-date linkages to project personnel, schedule, and technical content**
- **Modeled document linkages & usage propagate in real-time - create linkages between documents and other modeled elements, including requirements, personnel & project schedule elements**
- **Project-wide content reusability & synchronization; e.g., reuse of a single mission description across many documents**
- **Versatility of presentation formats, while referencing the single-source-of-truth content e.g., same requirement(s) can be presented in a table, diagram, or paragraph**
- **Project-wide nomenclature definition - common repository of acronyms, abbreviations, units & glossary terms**



- **Functional decomposition provided many benefits**
 - Early validation of requirements
 - Visibility for the phase leads to perform cross system analysis
 - More efficient process for mission planning
- **MBSE scaling to a large user base creates many new problems**
 - So far only observed on Europa and ARRM (to my knowledge), the scalability of using MBSE tools like MagicDraw to more than about 10 users creates significant model configuration control issues
 - The ARRM SE team dealt with this by limiting access directly to the core MBSE tool (MagicDraw) to a small subset of system engineers and providing editing to the rest of the team through a more controlled web based interface (View Editor)
- **Accommodating external partners is difficult but manageable**
 - Many JPL tools have significant impediments for bringing on external users (licensing fees, firewall access, proprietary data control)
 - Cloud based use of flexible commercial software (Atlassian) mitigated these issues substantially



- **Important to balance clear ownership and broad cognizance**
 - Ultimate process resulted in an efficient limited signature set with a highly visible process of identifying and logging concerns
- **Clarity between “work to” and “in work” documents is important**
 - Both the “work to” and “in work” documents were accessibly and clearly identified through the project dashboard
 - MBSE enabled easy collaboration on current “in work” documents
 - “Work to” documents still clearly defined in a conventional released document file structure
- **Cross referencing capability was extremely useful**
 - Allowed use of common information elements (like the mission description) across multiple documents
 - Allowed generation of tailored released subcontract requirements quickly
- **Did not fully synchronize releases**
 - Decision made for expediency in release process
 - Resulting inconsistencies were small, manageable, and less than the past

Future (Power Propulsion Bus)



Phase 1 Plan

Establishing deep-space leadership and preparing for Deep Space Transport development



		Deep Space Gateway Buildup			
EM-1	Europa Clipper	EM-2	EM-3	EM-4	EM-5
2018 - 2025					2026
SLS Block 1 Crew: 0	SLS Block 1B Cargo Europa Clipper (subject to approval)	SLS Block 1B Crew: 4 CMP Capability: 8-9T 40kW Power/Prop Bus	SLS Block 1B Crew: 4 CMP Capability: 10mT Habitation	SLS Block 1B Crew: 4 CMP Capability: 10mT Logistics	SLS Block 1B Crew: 4 CPL Capability: 10mT Airlock
Distant Retrograde Orbit (DRO) 26-40 days	Jupiter Direct	Multi-TLI Lunar Free Return 8-21 days	Near Rectilinear Halo Orbit (NRHO) 16-26 days	NRHO, w/ ability to translate to/from other cislunar orbits 26-42 days	NRHO, w/ ability to translate to/from other cislunar orbits 26-42 days
Gateway (blue) Configuration (Orion in grey)			Cislunar Support Flight	Cislunar Support Flight	

These essential Gateway elements can support multiple U.S. and international partner objectives in Phase 1 and beyond

Known Parameters:

- Gateway to architecture supports Phase 2 and beyond activities
- International and U.S. commercial development of elements and systems
- Gateway will translate uncrewed between cislunar orbits
- Ability to support science objectives in cislunar space

Open Opportunities:

- Order of logistics flights and logistics providers
- Use of logistics modules for available volume
- Ability to support lunar surface missions

10